PREFACE: CEOS: THE CLIMATE AND EASTERN OCEAN SYSTEMS PROJECT

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1. CEOS : AN INTERNATIONAL NETWORK WORKING ON CLIMATE AND FISHERIES

The injection of millions of tons of greenhouse gases into the earth's atmosphere may be viewed as a gigantic experiment aimed at exploring the earth's reaction to such challenge. Unfortunately, this experiment is run without proper "controls", and hence the heated debates about the actual impact of those gases may last too long, beyond the time where the "experiment" should be called off. The international scientific community is forced, however, to address this problem in spite of the lack of scientific controls. One way to address this is through the comparative method, a major tool in those disciplines in which experiments are hard to perform, e.g. evolutionary biology (Mayr, 1982), fisheries science (Bakun 1985, 1996).

Given the importance of the four major upwelling systems off Peru, Chile, California, Northwest and Southwest Africa both as sources of fish and as CO2 "pumps", scientists from the Pacific Fisheries Environmental Group (PFEG), of the National Marine Fisheries Service (NMFS), the Institut Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM), and the International Center for Living Aquatic Resources Management (ICLARM) and partners from other institutions, have teamed up to investigate these systems in the context of global changes, through a project called CEOS (Climate and Eastern Ocean Systems), funded by NOAA and ORSTOM. Several national research laboratories working on similar systems are associated with this project through a cooperative agreement with ORSTOM. The African research institutes associated to the CEOS project are the Institut Scientifique des Pêches Maritimes (ISPM) in Morocco; the Centre de Recherches Océanographiques d'Abidjan (CROA) in Côte d' Ivoire; the Fisheries Research Utilization Branch (FRUB) in Ghana; the Centre de Recherches Océanographiques de Dakar-Thiaroye (CRODT) Sénégal, and the Sea Fisheries Research Institute (SFRI) in South Africa which focus on regional case studies of climatic variability, coastal ecosystem dynamic and associated human responses. In Latin America, the Instituto del Mar del Peru (IMARPE) in Peru; the Instituto de Fomento Pesquero (IFOP) and the Universidad Catolica de Valparaiso in Chile are also involved in this project. The collaboration of scientists from these institutes with the CEOS project was also partly funded by the Scientific

Committee on Dynamics and Use of Renewable Resources (DURR) of ORSTOM and PNDR (Programme National sur le Déterminisme du Recrutement).

2. BACKGROUND

The great stocks of sardines and anchovies, and other small pelagic fishes, account for about one third of the world's yield of marine fish and are of key economic importance in many nations. Production from these great stocks depends upon a delicate balance of physical ocean processes. The optimal environmental window for small pelagic fish depends upon a triad of physical factors (Bakun, 1996) : *enrichment processes* that lead to the production of the zooplankton upon which the young stages depend for food ; *concentration processes* that aggregate foods and thereby increase their availability to growing larvae ; and *retention processes* that keep the young in their favored nursery habitat. Without a doubt, global heating will alter this triad of physical processes. These processes are functions of atmospheric forcing, ocean dynamics, and fresh water inflow ; all of which are expected to be altered by climate change.
The most immediate response to greenhouse warming would occur within the atmosphere rather than within the ocean, affecting the wind field over the ocean, and hence, patterns of upwelling. Bakun (1990) presents evidence that this is already occurring over the past several decades. Thus global climate change could substantially alter these factors that determine favorable reproductive habitat long before ocean temperature changes due directly to greenhouse warming may be evident. Some initial scenarios are already available. For example, Bakun (1990) has argued that one consequence of increased greenhouse effects that can be confidently expected is that temperature gradient between the ocean and the continents will increase during the Spring-Summer upwelling seasons in these systems. This would be reflected in increased alongshore wind and enhanced sea breeze circulation, which would impact recruitment (Mendelssohn and Mendo, 1987). Evidence exists for an "optimal environmental window" (Cury and Roy 1989; Cury *et al*. 1995) with respect to wind effects such that changes in characteristic wind speed may disrupt finely tuned reproductive strategies of the small pelagic fishes.

A former project on climatic change and pelagic fish stock dynamics was previously done in West Africa (Mauritania, Senegal, Côte d'Ivoire and Ghana) (Cury and Roy 1991). One important result of this project was to establish the existence of recurrent patterns between the environment and the pelagic fish dynamics. The aim of the CEOS project was to enlarge this analysis through a comparative approach and to generalize previously obtained results. Upwelling ecosystems in the Pacific are dominated by large interyear variability whereas in the Atlantic they are characterized by a more seasonal variability. To compare the dynamics of two

different functioning upwelling systems would help to understand the impact of environmental constraints on pelagic fish dynamics. Through the CEOS network it was possible to assemble and compare knowledge and data that were collected during several decades in the different upwelling areas.

Eastern ocean upwelling ecosystems present certain advantages that may make the study of effects of climate change on marine ecosystems particularly tractable; thus the study may serve an even wider purpose as an illustration of the sorts of impacts that could affect a variety of more complex marine ecosystems. As environmental changes may affect fish population dynamics in many ways and at different time and space scales, local case studies and comparative global studies are presented for the different upwelling systems. A better understanding of the links between environmental changes and fish population response is expected using various approaches. By analyzing time series data from similarly functioning regional ecosystems distributed over the globe, we hope to tease out the significant global trends from within the "noise level" of naturally-occurring regional climatic variability.

Disentangling global versus local environmental changes appears to be a major challenge when analyzing environmental time series. New statistical techniques are developed and applied to environmental indices relevant for fish population dynamics in order to extract trends and sometime changing seasonal patterns. Another approach to identifying trends in ecosystem processes will be through the construction of sequences of trophic models of the ecosystems and by computing the values of indices expressing their emergent properties. Emphasis is given to the theory of Ulanowicz (1986) and to the concepts of maturity, stability, and especially "ascendancy", an emergent attribute of ecosystem models that encompasses their size as well as their structure. The ECOPATH II software of Christensen and Pauly (1992) is used for construction of several models for each of the investigated systems.

Human activities facing local and global changes are also studied. The exploitation of marine renewable resources in the different upwelling areas appears to be a real challenge due to the fact that these resources are unstable. This will give some new insights on how human activities are coping with economical and social change at different levels of organization, from which different new approaches on how to use unstable renewable resources may be derived.

The general theme copes with variability and instability: instability of the environment in which the resources evolve, intrinsic instability of the pelagic fish stocks and uncertainty which govern the economic exploitation of a natural resource. All these dynamics are intrinsically linked. The

CEOS project is a multi-disciplinary project where physical, biological and economical aspects focus on this common theme.

3. GOALS AND OBJECTIVES OF THE CEOS PROJECT

The CEOS project is an international collaborative study of potential effects of global climate change on the living resources of the highly productive eastern ocean upwelling ecosystems and on the ecological and economic issues directly associated with such effects. A major focus of the study are the clupeoid fishes (anchovies, sardines, etc.) that are heavily exploited in the world's large marine ecosystems and which have recently been exhibiting episodes of collapse, rebound, or switches in dominance. The major objectives of the CEOS project are thus to (1) assemble, summarize, and analyze the data record of the past four decades regarding the four eastern ocean boundary upwelling ecosystems mentioned above and other upwelling areas, (2) to apply the comparative method to identify key physical processes and ecosystems responses, (3) to resolve underlying global-scale trends that in each individual regional system may be obscured by local interyear and interdecadal variability, (4) to investigate the relationship of these global trends to accumulating greenhouse effects, (5) to construct scenarios for future consequences of global climate change on upwelling resources, and (6) to analyze and project ecological and social impacts on associated human activities and values.

More generally CEOS is aimed at promoting scientific exchanges on the theme of the environment, the resource and the fisheries in upwelling areas and consequently to:

- promote relevant scientific themes on the environment, on marine resources and on fisheries;
- develop research and to promote scientific exchanges between developed and developing countries;
- promote the multidisciplinary approach in the management of the marine renewable resources;
- exchange data, methods and models in order to improve scientific knowledge;
- promote comparative ecosystem analyses in order to generalize process or to identify specificities in the environmental, the ecological or the economical dynamics;
- consider news ways for managing fisheries that take into account social and economic processes that are involved in fisheries;

4. LINKAGES OF THE CEOS PROJECT

The CEOS project addresses most of the strategic and integrating priorities listed in the U.S. "Global Research Program Priority Framework", especially the "Ecological Systems and Dynamics" category, and addresses in some way most of the issues listed under that category: e.g., "(assembly and analysis of) Long-Term Measurements of Structure/Function", "Response to Climate and Other Stresses", "Interactions Between Physical and Biological Processes", "Models of Interactions, Feedbacks, and Responses", "Productivity/Resource Models", etc.

The project is designed within the general framework of the International Program of Ocean Science in Relation to Living Resources (OSLR), which is co-sponsored by the Intergovernmental Oceanographic Commission and the Food and Agriculture Organization of the United Nations (Bakun et al. 1982). It can be considered an initial effort in the newly proposed subprogram of OSLR and Ecosystem Dynamics and Living Resources (EDLR). Elements of CEOS directly related with "recruitment" constitute contributions to the Sardine-Anchovy Recruitment Project (SARP), a major component of the International Recruitment Program (IREP) of OSLR. It is also involved in the GLOBEC/SPACC initiative and in the Programme National pour le Déterminisme du Recrutement (PNDR GLOBEC-FRANCE, France).

5. THE MONTEREY MEETING

The present multi-authored book summarizes the effort of a three year research activity of the CEOS participants. It presents the results of the first CEOS international conference held in Monterey (California) at PFEG (Pacific Fisheries Environmental Group) in September 1994 where fifty CEOS participants did exchange their results. The book is composed of thirty papers ranging from descriptive and comparative analyses of the major upwelling ecosystems, presentation of new statistical analyses and modeling techniques, to the analysis and modeling of human activities exploiting renewable resources. We hope that the CEOS network has reached, through the present book and the other activities, some of the ambitious objectives that were shared at the beginning!

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